

What is claimed is:

1. A method for manufacturing a semiconductor device, the method comprising:

forming a dielectric layer on a semiconductor substrate;

forming a metal layer on the dielectric layer;

5 oxidizing an exposed surface of the metal layer at a first temperature so that the an exposed surface of the metal layer is changed into an oxide film while maintaining a portion of the metal layer between the substrate and the oxide film; and heating the metal layer and the oxide film at a second temperature higher than the first temperature in an oxygen atmosphere, after oxidizing an exposed surface of the metal layer, wherein the second temperature is sufficiently high to change a
10 predetermined electrical property of the interface between the metal layer and the semiconductor substrate.

2. The method as claimed in claim 1, wherein the metal layer is an upper
15 electrode of a capacitor.

3. The method as claimed in claim 2, wherein the metal layer is formed of a material selected from the group consisting of iridium (Ir), rhodium (Rh), palladium (Pd), osmium (Os), and any combination of Ru, Ir, Rh, Pd, and Os.
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4. The method as claimed in claim 3, wherein the dielectric layer is formed of a material selected from the group consisting of Ta₂O₅, SrTiO₃ (STO), (Ba, Sr)TiO₃ (BST), PbTiO₃, Pb(Zr, Ti)O₃ (PZT), SrBi₂Ta₂O₅ (SBT), (Pb, La)(Zr, Ti)O₃, Bi₄Ti₃O₁₂, and BaTiO₃ (BTO).
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5. A method for manufacturing an integrated circuit capacitor, the method comprising:

forming a metal layer on a semiconductor substrate;

oxidizing an exposed surface of the metal layer at a first temperature so that
30 the an exposed surface of the metal layer is changed into an oxide film while maintaining a portion of the metal layer between the substrate and the oxide film; and

heating the metal layer and the oxide film at a second temperature higher than the first temperature in an oxygen atmosphere, after oxidizing an exposed surface of the metal layer, wherein the second temperature is sufficiently high to change a predetermined electrical property of the interface between the metal layer and the semiconductor substrate.

6. The method as claimed in claim 5, wherein the metal layer is sufficiently oxidized by the oxidizing an exposed surface of the metal layer so that the oxide film is substantially resistant to further oxidation during the heating the metal layer and the oxide film at a second temperature higher than the first temperature.

7. The method as claimed in claim 5, wherein the first temperature is selected to be sufficiently high and a time duration for oxidizing is selected to sufficiently long to sufficiently oxidize the metal layer so that the roughness of the upper surface of the metal layer is not substantially changed during the heating the metal layer and the oxide film at a second temperature higher than the first temperature.

8. The method as claimed in claim 5, wherein the first temperature is selected to be sufficiently high and a time duration for oxidizing is selected to sufficiently long to sufficiently oxidize the metal layer to render it substantially resistant to further oxidation during the heating the metal layer and the oxide film at a second temperature higher than the first temperature.

9. The method as claimed in claim 5, wherein the first temperature is selected to be sufficiently low and a time duration for the oxidizing an exposed surface of the metal layer is selected to sufficiently short so that the roughness of the upper surface of the metal layer is not substantially changed.

10. The method as claimed in claim 5, wherein the first temperature is sufficiently low to avoid changing the electrical properties of the interface between the metal layer and the semiconductor substrate.

11. The method as claimed in claim 5, wherein the metal layer is formed of a material selected from the group consisting of iridium (Ir), rhodium (Rh), palladium (Pd), osmium (Os), and any combination of Ir, Rh, Pd, and Os.

- 5 12. The method as claimed in claim 11, wherein the dielectric layer is formed of a material selected from the group consisting of Ta_2O_5 , SrTiO_3 (STO), (Ba, Sr) TiO_3 (BST), PbTiO_3 , $\text{Pb}(\text{Zr}, \text{Ti})\text{O}_3$ (PZT), $\text{SrBi}_2\text{Ta}_2\text{O}_5$ (SBT), $(\text{Pb}, \text{La})(\text{Zr}, \text{Ti})\text{O}_3$, $\text{Bi}_4\text{Ti}_3\text{O}_{12}$, and BaTiO_3 (BTO).